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Synoptic Scale Influences on Increasing Summertime Extreme Precipitation Events in the Northeastern United States

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SUMMARY

Over the past 15 years, the northeastern United States has seen a statistically significant increase in the frequency of extreme precipitation events that is larger and more widespread than anywhere else in the country. This increase in events is more likely to be associated with frontal and low-pressure systems, rather than being caused by more tropical cyclones impacting the region.

BACKGROUND

Extreme precipitation events are characterized by a statistically exceptional amount of precipitation falling in a given time period as compared to climatology. Varying definitions of extreme precipitation can be found in the literature based on different time and spatial scales and statistical methods. Regardless, extreme precipitation events need to be monitored and predicted because of their local and regional impacts, such as major floods and landslides. This study examines changes in the occurrence of such events in the northeastern United States, demonstrating that they are becoming more frequent.

Introduction

Extreme precipitation events can have a large impact on society through flooding that can result in property destruction, crop losses, economic losses, the spread of water-borne diseases, and fatalities (Handmer et al., 2012). However, there is considerable uncertainty regarding how such events may change in the future (IPCC, 2013; Janssen et al., 2014). Much information can be gained by studying past events and how they have changed over time. While observations indicate that extreme precipitation events have increased in the contiguous United States, the largest and most widespread increase has been observed during the summer in the northeastern United States, encompassing an area from southeastern New York to northern Maine. The trend in northeastern U.S. extreme precipitation events carries a statistical significance of 99 percent and has been confirmed in multiple datasets (e.g., Agel et al., 2015; Frei et al., 2015; Collow et al., 2016). The study of extreme precipitation events is complicated by the wide range of meteorological causes, including extratropical cyclones, tropical cyclones, frontal systems, and mesoscale convective systems (Konrad, 2001; Kunkel et al., 2012; Agel et al., 2015). Using NASA's Modern-Era Retrospective Analysis for Research and Applications – version 2 (MERRA-2), observed extreme precipitation events in the northeastern U.S. were classified by their meteorological cause in order to evaluate how the different types of events have changed over time. Extreme precipitation events were defined as occurring when the amount of rainfall is greater than 90 percent of corresponding values for the calendar day of the year based on observations from the NOAA Climate Prediction Center (CPC) gridded Unified Gauge-Based Analysis within a climatology period of 1981 through 2010.

Time Series of Extreme Precipitation Events

As seen by the black line in all panels of Fig. 1, which shows the total number of extreme precipitation events per summer, extreme precipitation events in the northeastern U.S. have become more common over time. The frequency of occurrence has increased by an average of 1.48 events per decade over the 35-year time period extending back to 1980, but it is evident from Fig. 1 that the number of events has increased over the last 15 years in particular.

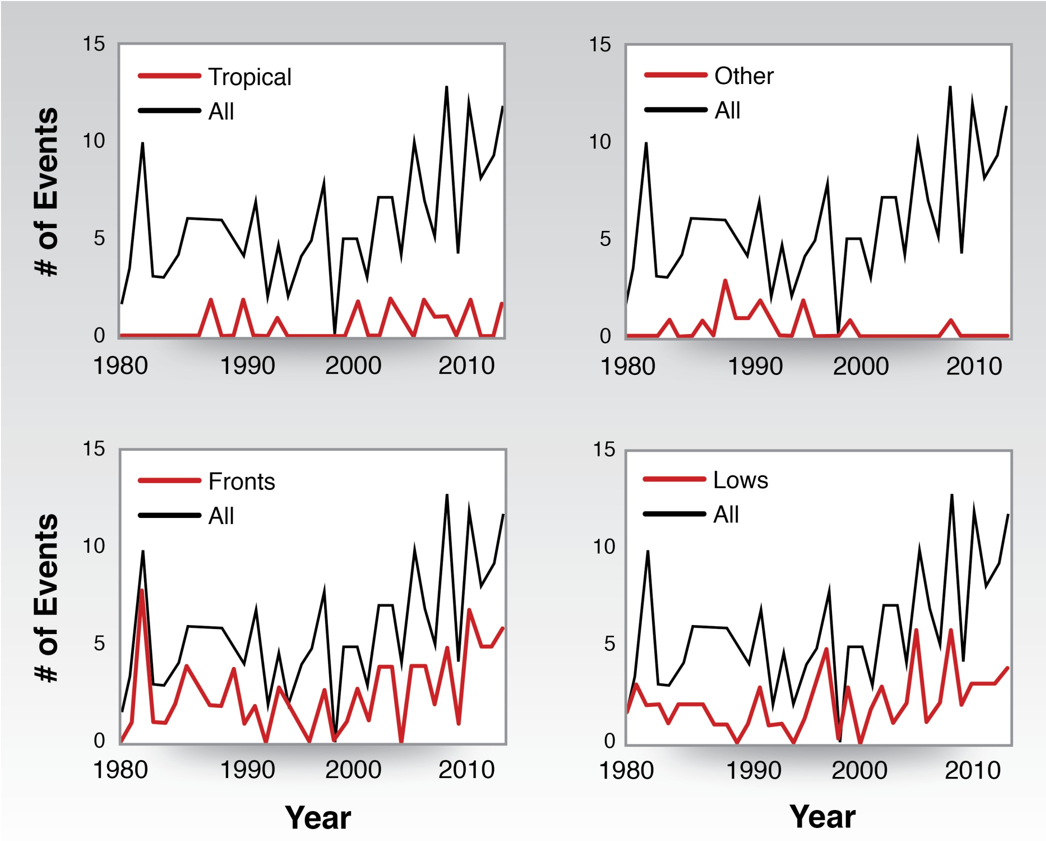

Figure 1. The total number of extreme precipitation events in the Northeast during June, July, and August as well as those caused by (a) fronts, (b) closed low pressure systems, (c) other types of systems (unassociated), and (d) tropical cyclones.

Each observed extreme event was classified as tropical, frontal, low pressure, or unassociated in the cases that did not fit into one of the first three categories. A tropical event was defined as one in which a storm identified by the National Hurricane Center's North Atlantic hurricane database (HURDAT) was co-located within 5° of the Northeast region, following the methodology of Kunkel et al. (2012). Frontal events were identified via the detection of a lower tropospheric wind shift and temperature gradient within the Northeast domain. Low pressure-related events were defined using the methodology of Pook et al. (2006), which requires a closed region of sea-level pressure below 1008 hPa and a negative anomaly in 500 hPa height or a closed area of 500 hPa height.

Tropical cyclones are known to cause the most intense extreme precipitation events in the Northeast (Konrad, 2001). Aside from a scarcity of tropical cyclones in the 1980s, there is little variability in the frequency of tropical-related extreme precipitation events, as there were never more than two events in a given year (Fig. 1a). Although there is interannual variability in the number of unassociated events, most occurred prior to the increase seen over the past 15 years (Fig. 1b). Unlike the tropical storm-related systems and the unassociated events, the number of events related to frontal systems has increased by 0.69 events per decade (statistically significant at 95%), accounting for roughly half of the observed increase in the total number of extreme precipitation events (Fig. 1c). The other half of the trend in the total number of events is related to a statistically significant increase in the number of closed low pressure systems (Fig. 1d).

Change in Composited Meteorology During Extreme Events

As frontal systems and closed low pressure systems are primarily responsible for the observed increase in extreme precipitation events, the atmospheric conditions surrounding these types of events were evaluated, as well as how the meteorological conditions have changed over time. This was done by compositing meteorological fields during observed extreme precipitation events that occurred within the second half of the analysis period, 1997 through 2014, and comparing with corresponding fields from the period of 1980 through 1996. Such compositing was done for all events as well as those related to a frontal or a low pressure system. As seen in Fig. 2a, an arc of statistically significant lower sea level pressure spanning from Maine to the Florida/Georgia border is seen in the more recent time period when all events are considered. This change over time primarily stems from the low pressure system-related events (Fig. 2b). While events related to a frontal passage are not associated with lower pressure over the Northeast in more recent years, there is a more pronounced area of lower sea level pressure in the Hudson Bay, which likely corresponds to the location of the parent low for the frontal systems (Fig. 2c).

There is an increased gradient in the height of 500 hPa in the more recent time period, with significantly lower heights just south of the region and significantly higher heights to the northeast (Fig. 3a). As with the sea level pressure changes shown in Fig. 2, the 500 hPa height changes are more related to low pressure events than frontal events. However, both event types are associated with higher heights northeast of the region in more recent years (Figs. 3b and 3c). Also, in the more recent time period, the area of lower 500 hPa heights lags slightly behind from the change over time at the surface. For extratropical cyclones, the spatial alignment of pressure patterns near the surface (sea level pressure) and in the middle troposphere (500 hPa heights) are related to the life cycle of the system and enhanced baroclinicity. The changes over time shown in Figs. 2 and 3 are indicative of a greater tilt in the pressure patterns in more recent years, with systems in the strengthening phase of their life cycle.

The Eady mean growth rate (Hoskins and Valdes, 1990) is a measure of baroclinic instability within the atmosphere that can be used as an analogue for storm tracks to determine how the path of a storm has changed over time. The parameter, which is a function of the atmosphere's wind and temperature profile, has been computed from MERRA-2 fields corresponding to each extreme precipitation event. As compared with the earlier period examined, more recent extreme precipitation events are characterized by a smaller Eady mean growth rate to the north and east of the region, and larger values to the south between 35° and 40°N. This is indicative of systems associated with extreme events having shifted south in more recent years (Fig. 4a). The smaller values in the Eady mean growth rate to the north and east are seen in both frontal and low pressure events. But only the low pressure events are associated with an increase in the Eady growth rate to the south in more recent years.

A low pressure system developing to the south in the more recent period, would advect warm, moist oceanic air more directly into the Northeast region, in a counter-clockwise motion about the center of the circulation. The interaction of the advected atmospheric moisture with topography would enable extreme precipitation events to occur. This southward shift in the storm track for extreme events caused by closed low pressure systems is a key factor for the observed increase in extreme precipitation events in the northeastern U.S. The composite anomalies for frontal systems are less conclusive and further work will aim to discover whether there has been an increase in the number of frontal systems moving through the region, or if frontal systems have become stronger over time.

In summary, observations indicate that there has been an increase in the frequency of extreme precipitation events in the northeastern United States. Although tropical cyclones can cause the most intense events in the region, the recent increase the frequency of extreme events is related to frontal systems and closed low pressure systems that are extratropical in nature. A southward shift in the tracks of low pressure systems has contributed to the increase in extreme precipitation events however there is still more to learn regarding frontal systems.

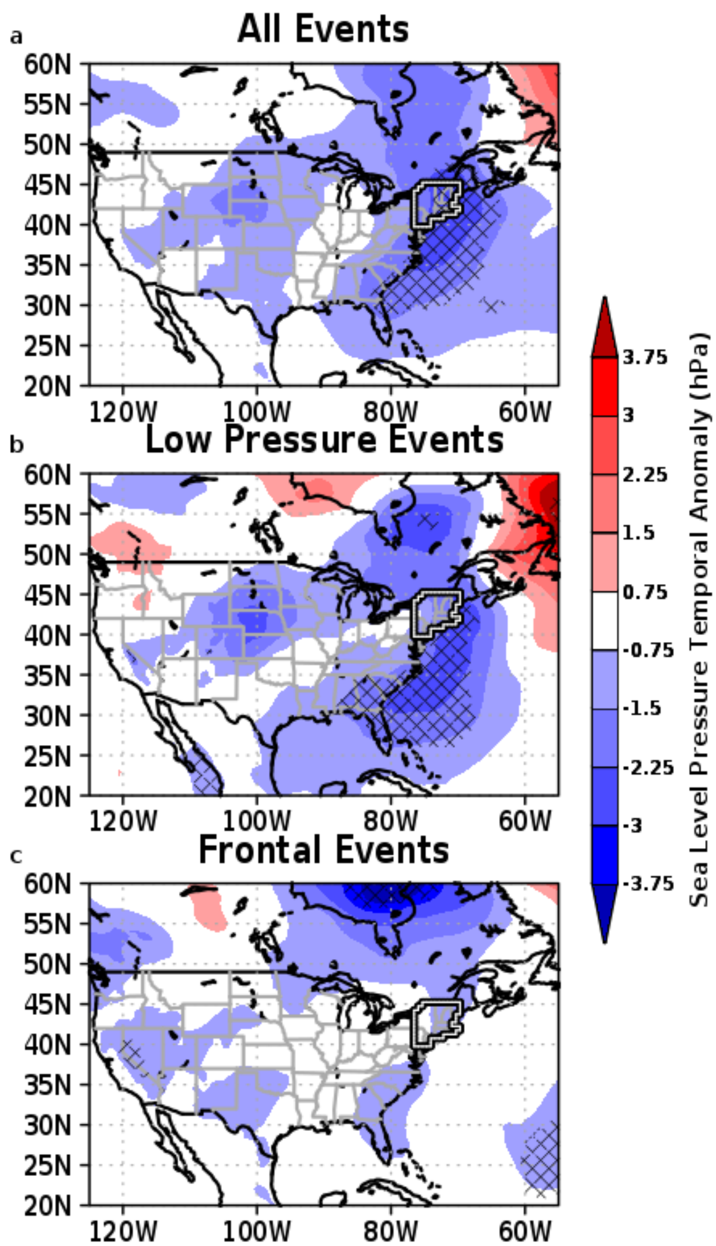

Figure 2. The difference in sea level pressure during observed extreme precipitation events in the Northeastern United States during 1997 through 2014 and 1980 through 1996 for (a) all events, (b) events caused by a low pressure system, and (c) events caused by frontal systems. Hatching denotes areas with a statistical significance of 95 percent.

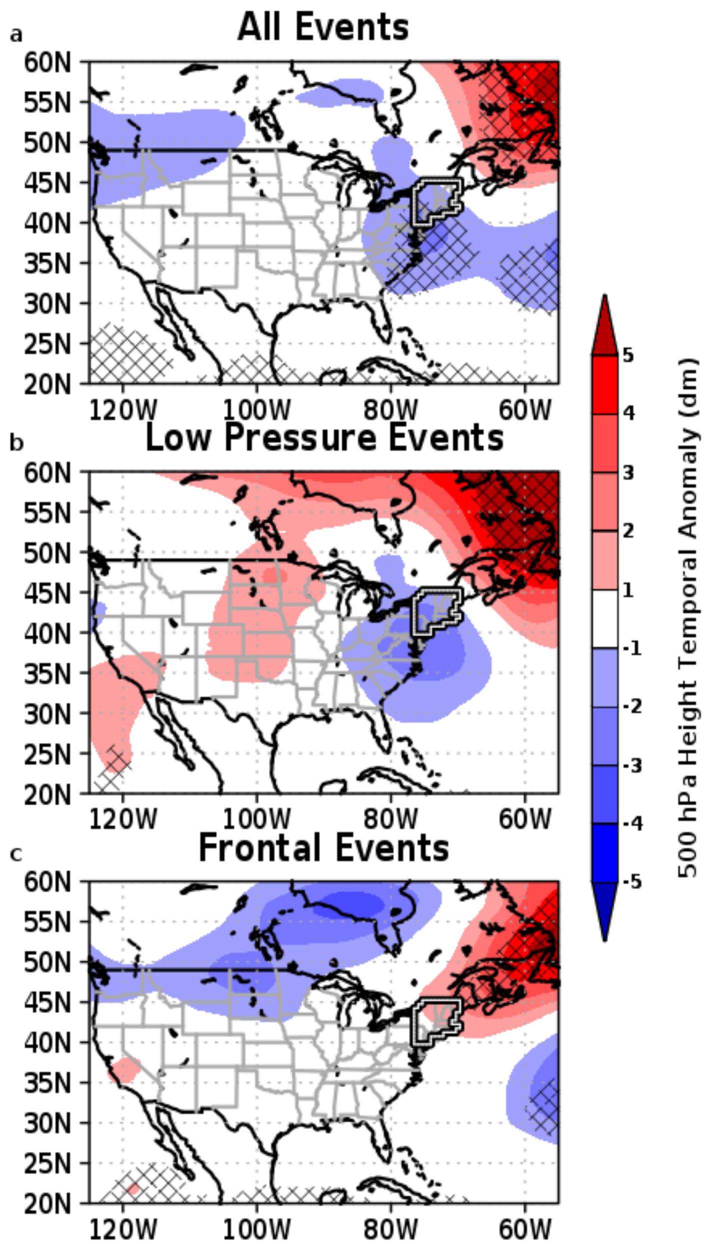

Figure 3. The difference in 500 hPa height on the day of an extreme precipitation event in the Northeastern United States during 1997 through 2014 and 1980 through 1996 for (a) all events, (b) events caused by a low pressure system, and (c) events caused by frontal systems. Hatching denotes areas with a statistical significance of 95 percent.

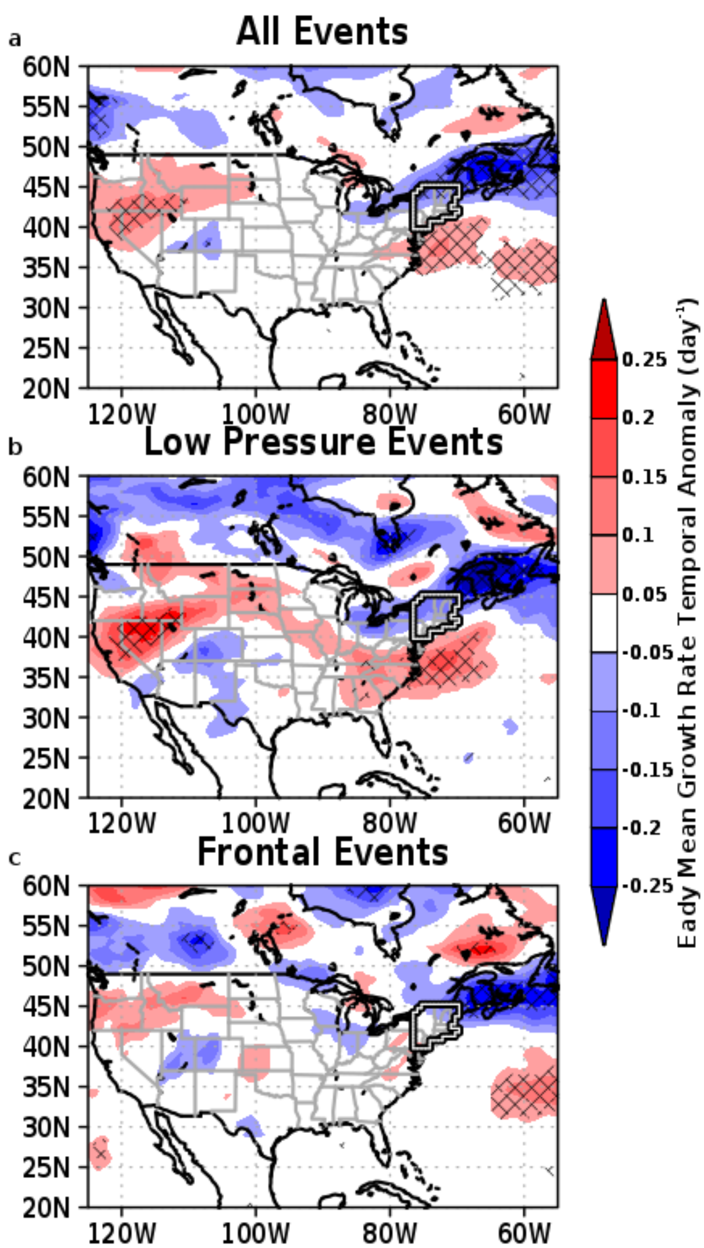

Figure 4. The difference in Eady mean growth rate on the day of an extreme precipitation event in the Northeastern United States during 1997 through 2014 and 1980 through 1996 for (a) all events, (b) events caused by a low pressure system, and (c) events caused by frontal systems. Hatching denotes areas with a statistical significance of 95 percent.

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